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CHALLENGES IN TRAIN EVACUATION MODELLING USING PATHFINDER

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ABSTRACT

In comparison to buildings, public transportation vehicles including passenger trains represent specific environments typical for cramped interior layouts with narrow aisles, limited number of exits, and various operation conditions resulting in non-standard exit paths such as direct egress to the track level. Therefore, in evacuation modelling, safety analysis of passenger trains may denote a challenging task, especially when using evacuation models originally developed for simulations of evacuation processes from buildings (such as Pathfinder). In this case, several issues can be encountered: lack of validation against relevant experimental data, missing features to simulate non-standard exit path, lack of knowledge which key parameters to adjust and how. This contribution addresses these issues while performing an egress simulation analysis of a rail car of double-deck electric unit class 471 (CityElefant) using Pathfinder. The analysis was based on a full-scale controlled evacuation experiment carried out in Prague in 2018. We introduce a technique for adjusting the Pathfinder model that simulates rail car egress to match the experimental results, and we include sensitivity analysis of key parameters influencing total evacuation time (TET). From the obtained results several conclusions can be drawn: a) Application of the SFPE curve for a speed-density relationship had a significant impact on TET due to narrow aisles and limited space available; b) The parameters of agent diameter and squeeze factor have to be handled together (when associating the agent diameter with the width of passenger shoulders, the value of squeeze factor must be decreased); c) While egressing to the track level, the time delay caused by the preparation and realization of the jump must be implemented adequately to different passenger abilities; d) The impact of seating preferences of passengers with heterogeneous moving abilities prevails the influence of maximal speed or diameter distribution on TET.

INTRODUCTION

Safety evacuation from cramped spaces with high-density crowds of heterogeneous demographics constitutes an important challenge in life safety assessments. Despite a simple layout, public transport vehicles (for example, passenger trains, ships, aircrafts, or motorcoaches) can be seen as unique environments with various operational conditions and potentially difficult and non-standard evacuation circumstances [1]–[8], and as such, they have also been subjected to development of specific evacuation models [9]–[14]. Taking into account the railway environments, in addition to special evacuation models developed to simulate the evacuation of passenger trains [9], [10], building evacuation models have been used for numerical predictions of exit time and simple evacuation scenarios in several research studies [15]–[20]. However, for this purpose, application of evacuation models originally developed for building design should be carefully considered, ideally supported, and validated using reliable experimental data.

In our previous research [21], we explored the ability of Pathfinder to simulate passenger train evacuation scenarios based on its validation against original experimental data sets obtained in a full-scale controlled evacuation experiment using a double-deck rail-car. As our simulations and analyses revealed, Pathfinder was possible to successfully use for the particular rail-car evacuation simulations, whereas some adjustments and modifications of the model were needed. In the current case study, we extend our investigations of several key aspects related to simulations in Pathfinder, which may be of interest when focusing on more specific and precise modelling issues, and we present a deeper insight in technical solutions employed.
Furthermore, the introduced model is investigated by means of sensitivity analysis to identify and interpret the influence of important aspects and features of the model on total evacuation time (TET). Sensitivity analysis is a powerful tool that provides deeper insight into the dynamics of the model and influence of parameters on the observable quantity [22], which is, in the scope of the evacuation dynamics, usually the TET [23]. In addition to the uncertainty investigation, the model is inspected by means of a variance-based analysis based on Sobolev indices [24].

EXPERIMENTAL AND SIMULATION BACKGROUND

To provide the context and research background, this section summarizes key information from our previous experimental and simulation evacuation study thoroughly described in [21]. For more details on, the interested reader is kindly referred to it.

In order to gather new experimental data sets on human behavior and movement characteristics and to survey the impact of various boundary conditions on the evacuation process, a full-scale evacuation experiment was conducted in 2018 in the Czech Republic using a class 471 double-deck electric unit (CityElefant) trailer car. The experiment consisted of 15 evacuation trials and 30 evacuation scenarios under various evacuation conditions with 91 participants. Participants were divided into two groups: homogeneous group (HOM) with people aged 18 to 38 years without any movement limitations (in good physical conditions); and heterogeneous group (HET), whose composition was proposed to emulate the composition of ordinary travelling population. In this HET group, 28% of the participants characterized passengers with movement limitations, represented by children, adults carrying a toddler, seniors, and passengers with physical disabilities (with crutches). To study the impact of various boundary conditions on the evacuation time, evacuation scenarios differed in various main exit widths (650 mm, 750 mm, 900 mm, 1100 mm, and 1340 mm) and exit types (exit to a high platform, to an open line using stairs, to an open line navigating a 750 mm drop), which were randomly changed to minimize the influence of learning effect. To eliminate undesirable variations not related to boundary conditions, participants had the same initial starting positions in all 15 trials.
To support our conclusions based on the experimental data, we created a Pathfinder model of one half of the rail-car in the described study [21]. An illustration of the rail-car layout and its model in Pathfinder is presented in Figure 1.

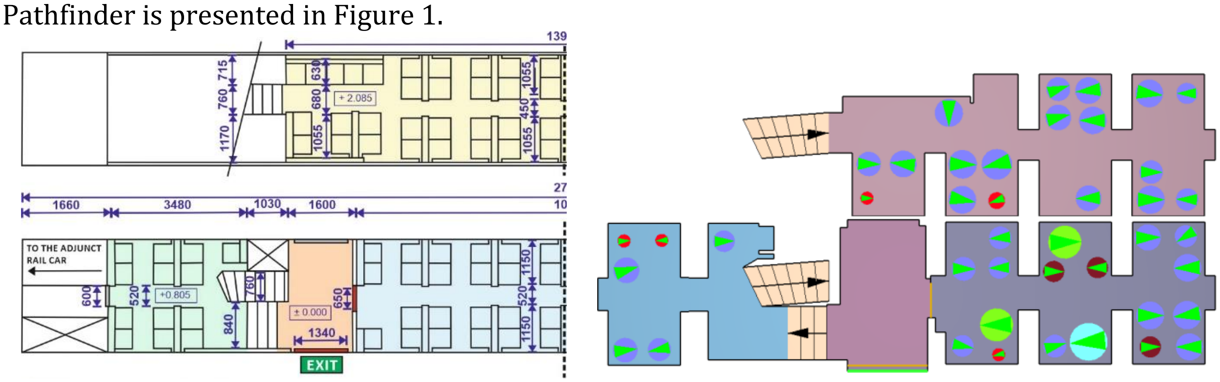

Figure 1: Layout of one half of the rail-car (left) and its model in Pathfinder (right).

For the purposes of the simulation, five agent profiles were defined.: “Without limitations”, “Children”, “Carrying a toddler”, “Seniors”, “With disabilities”. The profiles differed in the distributions of maximal velocity and diameter, in the definition of behavior related to non-standard exit paths, and in few other nuances (see Table 13 in [21] for detailed setup of parameters). Building the model, the following issues specifically related to the experimental rail-car environment were encountered.

Cramped interior layout with narrow aisles

Most of the rail-car layout consists of narrow aisles, either directly defined by internal staircases or corridors connecting individual parts of the car or indirectly emerging as a space between individual seats. The seats themselves restrict motion of passengers only partially. Especially when shifting from the seating positions towards the central aisle, it was commonly observed in our experiments that passengers moved along a seat with their center of mass over it. Several options for modelling rail-car seats in Pathfinder were studied numerically in [25]. Surprisingly, the most realistic solution compared to the experimental data and observations was to omit the seats and model seat-backs as an impenetrable obstacle or wall.

The cramped interior layout also appears to increase the effect of agents’ diameter on the simulation results. To analyze how much the agent blocked the space to others, the agent’s diameter was set equal to the exact shoulder width of the modelled passenger (the participant in the experiment). This approach, however, had to be accompanied by further adjustment of geometry-related agent properties. For agents of the types “Carrying a toddler” and “With disabilities”, a high value of the diameter (0.62 m and 0.71 m respectively) was compensated by reducing the default value of the squeeze factor (`OccProfile.MIN_SQUEEZE_FACTOR_CONST`) from 0.7 to 0.6. Nevertheless, the minimum diameter to which such agents could reduce their widths due to narrow geometries (`OccProfile.GEOM_DIAMETER`) was set to 0.5m instead of the default value of 0.33 m.

Non-standard exit paths

Considering an emergency in rail-car environments, especially outside stations, different exit types must be considered. Aside the exit to a platform (which can be seen as similar to an exit from a building), some kind of equipment (e.g., staircase of variable steepness) or performing a jump down may be necessary for egressing to an open line. The latter appears to be of importance in heterogeneous populations, as their abilities to overcome such jumps significantly differ from passengers without any movement limitations. It was observed in our experiment that navigating the 750mm drop between the train floor and the track level caused significant delays for certain passengers (a detailed summary can be found in Table 11 in [21]). The time delays were mainly caused by hesitation of the passengers and their preparations for the jump and by balancing processes at the terrain level after the jump was performed. This delay modifications were also implemented in our Pathfinder model and more details are explained below in section Technical Solution in Pathfinder.

Specifically defined initial positions

It is important to investigate the evacuation processes and evacuation time under various initial positions of agents. However, in a rail-car, the positions of passengers cannot be absolutely arbitrary, but are fixed to defined seating positions. Our solution for an automatic random choice of seating positions is presented below in section Technical Solution in Pathfinder.

Sources of Randomness

The primary purpose of the described Pathfinder model was to mimic the mentioned experiment as much as possible. Related to that, three independent sources of variance in evacuation time were identified:

1. **Variance caused by different seating positions.** In the experiment, this source of variance was eliminated due to identical starting positions in all trials. However, the possibility of seating agents randomly is important for further safety and sensitivity analysis.
2. **Variance caused by uncertainty in the properties of the passengers.** Even passengers of the same type had different physical abilities or psychical preferences (size, desired velocity, social distancing). This variation was suppressed in the experiment (all trials were performed with the same group of participants), but it is important to investigate the evacuation with respect to those possible variations.
3. **Variance caused by uncertainty in human behavior.** Repeating the same evacuation with the same people starting from the same initial positions may also result to different trajectories due to high variance in human behavior. However, such repetition in experiments is influenced by learning effect, which must be considered. This level of randomness is usually implemented in microscopic evacuation models by means of randomized decisions made by agents, usually in case of conflicts when more agents attempt to enter the same space.

In our studies, it was necessary to control all three sources of randomness individually and automatically. The technical solution, how to achieve this in Pathfinder is presented in the following section.

TECHNICAL SOLUTION IN PATHFINDER

One of the great advantages of Pathfinder is that it is focused on user friendliness; the user does not have to "code" the model as everything is typically set via the GUI. Nevertheless, when studying the model parameters in the extent of this contribution, it is necessary to run the simulations in an automated way with the ability to change some key parameters automatically within an algorithmic cycle. This was achieved by creating a Python script which modified the Pathfinder simulation input file [26] (Chapter 11). Then it run the simulations through the command line [27] (Section 11.2.1) in a cycle storing key results of the simulations. Modifications of the input file were performed according to Technical reference [26].

Preparation of the Input File Template

By means of the GUI a template input file was created, containing all necessary information required (geometry, profiles, possible agent initial positions, and others).

Geometry

Three geometries of the rail-car were prepared, one for each exit type, differing only by the environment behind the main exit (platform, stairs, jump). The appropriate nodes that defined the main exit door were identified. Shifting those nodes allowed one to vary the width of the main door. The positions of the rail-car seats were manually marked and stored in a CSV file for further random position generation.

Profiles

Five agent profiles were defined according to the above-mentioned passenger types in the HET group, defining key parameters and functions related to the agent type. Because the parameters of individual occupants were generated within the Python script, the link of an agent to a given profile served rather for visualization purposes.

Behaviors

The behaviors feature served as a mechanism for the implementation of the jump-induced delay observed during the experiment. Behavior with index `0: {"script": "goto exit any"}` was used for geometries with a platform or with stairs and for agents of the type "Without limitations" in

the case of jump geometry, since no delays were observed for passengers of this type. Other four behaviors were used to implement the measured delays for agents of the types "Children", "Carrying a toddler", "Seniors", and "With disabilities" in the following manner:
`{"goto point [in front of the jump]; wait [hesitation delay]; goto point [behind the jump]; wait [balance delay]; goto exit any"}.`

Occupants

Typical occupants of each profile were generated to serve as a template for further occupant inputs. The following properties of the `OccProfile` were set while generating the occupants: `MAXVEL`, `DIAMETER`, `FUNDAMENTAL`, `MIN_SQUEEZE_FACTOR_CONST`, `GEOM_DIAMETER`, and `PRIORITY_LEVEL`. Other properties were beyond our investigations, but can be easily changed from defaults as well. When generating new occupants, the following properties were set:

- `"loc":` initial position chosen from the predefined list of possible seating positions, stored in a separate CSV file (overlapping and collisions with geometry were checked),
- `"profile":` according to the desired agent type,
- `"behavior":` to influence potential jump-related delays,
- `"rseed":` a random seed influencing random processes during simulations,
- `"OccProfile."` properties mentioned above, when differing from the profile definition.

Controlling Randomness

The above-mentioned concept allowed us to control the randomness of key features of the simulation without the necessity of manually changing the chosen properties. Theoretically, it is possible to capture some correlation between the chosen parameters. As an example: Suppose that some correlation between maximal velocity and size of pedestrians was revealed. An external random vector generator can be used to generate the non-independent pairs (`MAXVEL`, `DIAMETER`). These pairs can then be input as parameters for individual occupants. In the scope of the presented study, the introduced concept was used primarily to control the three sources of randomness in the model.

Variance caused by different seating positions

Similarly to Pathfinder option "Randomize Occupants' Positions", the initial positions of individual agents were generated randomly; however, in our case, the positions were chosen from a finite predefined list stored in the CSV file. For the purposes of this contribution, a uniform distribution was used. A more sophisticated generator that considers passenger seat preferences would require additional study to be captured.

Variance caused by uncertainty in passenger properties

The selected properties of agents (`"OccProfile."`) were randomly generated according to the chosen distributions, analogously to the Pathfinder option "Randomize".

Variance caused by uncertainty in human behavior

Certain variance in agent behavior can be modelled by changing the parameters of the occupants related to individual decisions and conflict solutions. This was achieved by random change of agents' properties `"rseed"` and `"OccProfile.PRIORITY_LEVEL"` before every simulation was run, while preserving other agent properties (parameters, positions). This enabled us to obtain various possible trajectories for given boundary and initial conditions. It is similar to calling the "Randomize" option for a group of agents with fixed parameters.

To capture the influence of individual sources of randomness on the variance of evacuation time, a series of simulations was performed. As a basic configuration, the platform scenario with a homogeneous group of passengers was taken with the same parameters and seating positions as in the described experiment [21]. For each source of randomness, 100 simulations were run for three exit widths with randomly generated values corresponding to the source. Specifically:

- **The positions** of the agents were randomly generated while keeping all the parameters and random seeds unchanged.
- The maximal **velocities** of all agents were regenerated from the chosen distribution with initial positions and random seeds unchanged.
- Random **seeds** and priority levels of the agents were randomized, but the positions of the agents and other parameters remained fixed.

The box-plots that illustrate the variance of evacuation time with respect to a given source of randomness are shown in Figure 2. We can see for an exit width of 0.65m (agents created a single line at the door) that the variance caused by these sources of randomness is comparable. However, with increasing exit width, the variance caused by the random seeds (inherent randomness of the model) vanishes, the variance caused by the velocity distribution decreases, but the variance caused by different seating positions significantly increases.

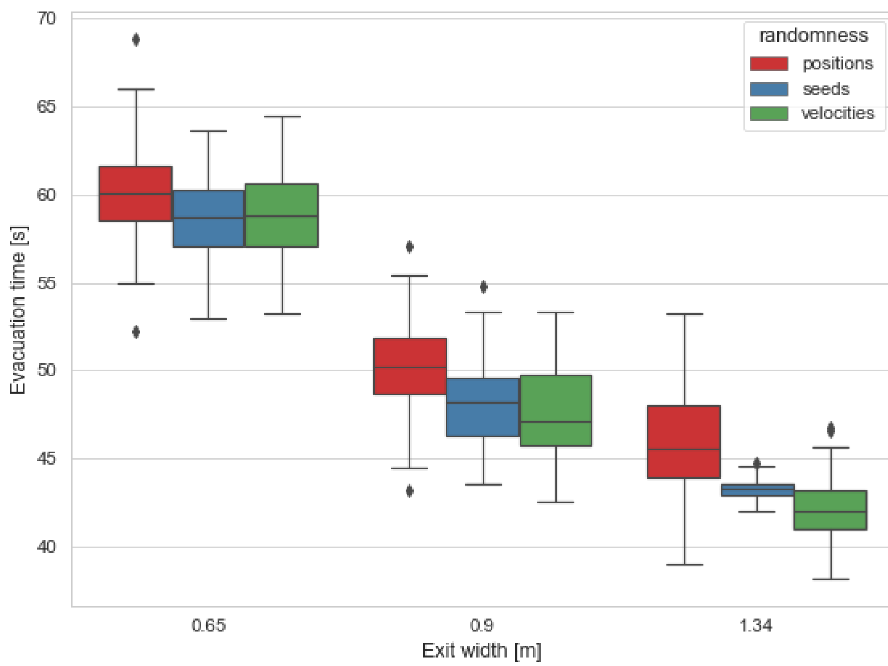

Figure 2: Influence of different sources of randomness on variance of TET.

SENSITIVITY ANALYSIS AND ITS IMPLICATIONS

This section presents key results of the analysis of the specific rail-car egress model presented above. The influence of important features and parameters was studied by means of a variety of simulations.

Velocity and SFPE Curve

The default behavior of Pathfinder for calculating an occupant's immediate velocity is to scale their maximum free-movement speed by a factor that depends on the local density via the standard SFPE fundamental diagram. However, in the case of our analysis, with normal walking speeds (1.2 – 1.5 m/s) this set-up appeared to overestimate the evacuation times compared with the experimental measurements; probably due to the high density of the agents in the cramped environment of the rail-car model. As described in [21], recording of the entire experiment allowed us to estimate the unrestricted movement speed of HOM passengers walking in a line to be 0.94 m/s with a standard deviation of 0.25 m/s. In order to mimic the experiment as much as possible, this value was set as the maximal velocity of agents of the type "Without limitations", while the influence of the SFPE fundamental diagram on the velocity was disabled, i.e., the parameter "`OccProfile.FUNDAMENTAL`" was set to a constant function equal to 1.

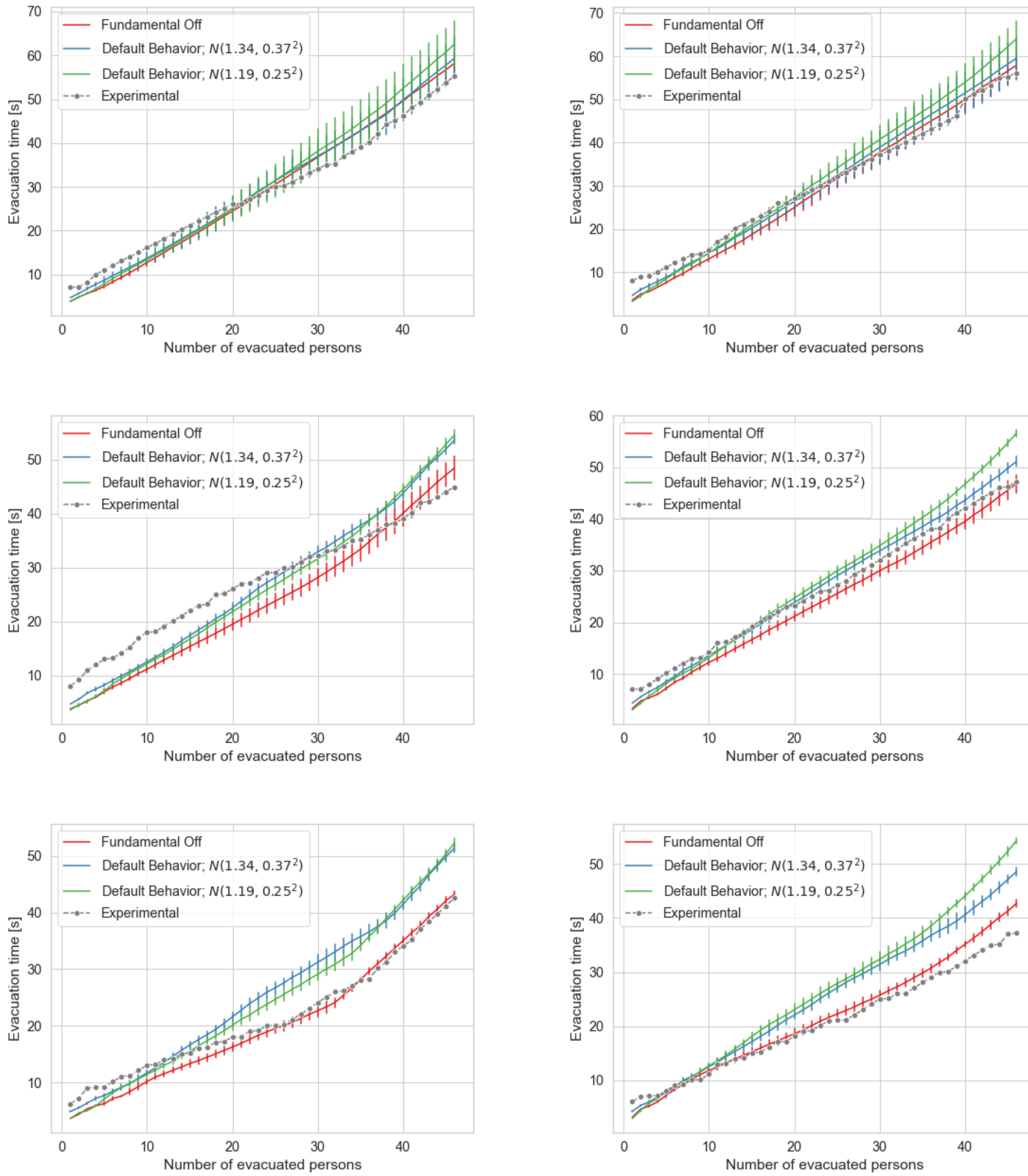

Figure 3: Evacuation times of individual occupants. The left column corresponds to the HOM group and the right column corresponds to the HET group. First row – 0.65 m exit width, second row – 0.90 m exit width, third row –1.34 m exit width. Vertical lines denote standard deviations.

Figure 3 shows a comparison of the evacuation times experimentally measured (dots) with three different settings of the maximal velocity distribution for the agent type "Without limitations" and "Carrying a toddler":

- **Red** – truncated normal distribution with mean 0.94 m/s, standard deviation 0.25 m/s, minimum 0.64 m/s and maximum 1.56 m/s with SFPE relation turned OFF. These values come from our experimental measurements and were used to mimic the experiment [21].
- **Blue** – truncated normal distribution with mean 1.34 m/s, standard deviation 0.37 m/s, minimum 0.60 m/s and maximum 2.08 m/s with the SFPE relation turned ON. These values were taken from [28] denoting maximal unimpeded velocity in free space.
- **Green** – truncated normal distribution with mean 1.19 m/s, standard deviation 0.25 m/s, minimum 0.69 m/s and maximum 1.69 m/s with SFPE relation turned ON, related to Pathfinder default based on [29].

The unrestricted movement speeds of other passenger types were not observed in the experiment [21], and therefore were set according to the literature with the SPFE relation turned ON: "Children" 1.32 m/s according to [30], "Seniors" 0.7 m/s in line with [31], "With disabilities" 0.94 m/s according to [32].

Each simulation scenario was run 40 times with different random parameters (occupant priority and random seed) to account for the inherent randomness of the model. The geometry with exit to a platform was used and three different exit widths were tested: 0.65 m, 0.9 m, and 1.34 m. From the graphs in Figure 3 we can observe that the wider the main exit is, the stronger is the effect of the evacuation time overestimation due to a density-related decrease in velocity using the SFPE relation.

Initial Seating Positions

Compared to buildings, initial seating positions of evacuees play a significant role while egressing a rail-car or other cramped interior consisting of narrow aisles that disable most of overtaking attempts. The concept of randomness-sources control allowed us to study the effect of different seating positions using Pathfinder simulations. To obtain enough data for our analysis, 100 different seating configurations were randomly generated for each exit type (platform, stairs, and jump) and exit width (0.65 m, 0.90 m, and 1.34 m) for both the HOM group and the HET group, adding up to a total of 1800 configurations. Agent parameters, such as maximum velocities or diameters, remained unchanged. Each configuration was run three times with different random parameters (random seeds and priorities), and the results were averaged to account for the inherent randomness of the model. The box plots that illustrate the evacuation times distribution are shown in Figure 4.

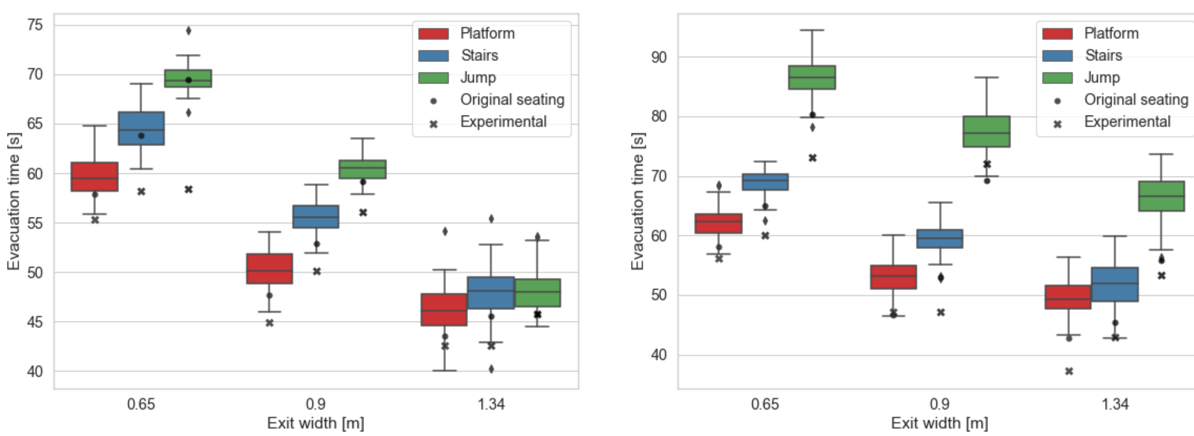

Figure 4: Distribution of the TET with respect to the seating of passengers. The plot on the left describes the HOM group, and the plot on the right outlines the results for the HET group. The crosses indicate the evacuation times measured in the experiment [21], and the bullets indicate the simulated evacuation times related to the original seating positions in the experiment.

As mentioned above, we can see a significant variance related to the randomness in the seating positions. An important observation is that both, the experimental evacuation time and the simulation evacuation time for original seating positions in the experiment, are significantly lower than the main mass of the TET distribution. One explanation can be that the experimental seating was inspired by a real sub-urban situation and thus reflected some natural spread of the passengers along the train. An advanced study of the seating preferences of passengers would be very beneficial to understand this effect more properly.

Some deeper insight into this issue gives us a study of a measurable effect on TET caused by different occupation density at the lower, middle, and upper deck. For this purpose, the simulation data investigating the influence of different velocities and using the SFPE relation in the model and presented in the previous section were sorted according to the TET for each geometry and each exit width. The ten fastest and ten slowest simulation runs were extracted. For each initial seating and deck, the relative load of the deck was calculated as a ratio between the number of occupants on a deck and the total capacity of a deck. The relative loads measured for the platform geometry and the HOM group are shown in Table 1. Other geometries as well as the HET group followed the same trend.

Table 1: Relative loads of each deck averaged over the ten fastest and ten slowest simulations.

	Evacuation time [s]		Upper deck load		Middle deck load		Lower deck load	
	Best	Worst	Best	Worst	Best	Worst	Best	Worst
0.65 m	57.1	62.3	0.64	0.73	0.65	0.65	0.77	0.65
0.90 m	47.5	53.1	0.60	0.77	0.73	0.69	0.77	0.58
1.34 m	42.7	49.5	0.65	0.74	0.65	0.75	0.76	0.58

The results revealed that the loads of the smaller middle deck do not substantially differ between the fastest and slowest simulations, while the loads of the upper and lower deck do. The agents in the fast simulations were situated more densely in the lower areas of the rail-car closer to the main exit, while the upper deck was loaded more heavily in the slower simulation runs. This holds true for both the HOM and the HET groups, and the difference becomes greater with increasing exit width. This finding is in line with the natural expectation that a faster evacuation would have more people sitting closer to the exit. The opposite implication does not necessarily hold since sitting everyone exclusively on the lower deck would lead to a greater chance of congestion.
In addition, the simulated TET's in the HET group were affected by the initial seating positions of passengers with movement limitations. The distribution of the "Senior" agents (that is, the agent type with the lowest maximum speeds) differed severely for the fast and slow simulations. Regardless of the exit type and exit width, the majority of the "Senior" passengers were seated on the upper deck during the slowest runs. Similarly, most of the "Senior" agents were initially located on the lower deck in the fastest simulations.

Global Sensitivity Analysis

The influence of the chosen parameters on TET was further studied by means of sensitivity analysis. This analysis was carried out by approximating Sobol's first-order and second-order sensitivity indices S_1 and S_2, as well as the total sensitivity index S_T via Saltelli's Monte-Carlo sampling method [24]. Again, three different exit widths of 0.65 m, 0.90 m, and 1.34 m were investigated. Due to the large number of samples required for the estimation, only the
geometry with a platform was considered in the analysis. The following model parameters were modified:

- mean of the maximum velocity distribution $\mu_{\text{vel}} \in [0.65, 1.3]$ m/s,
- standard deviation of the velocity distribution $\sigma_{\text{vel}} \in [0.0, 0.5]$ m/s,
- standard deviation of the diameter distribution $\sigma_{\text{diam}} \in [0.0, 1.0]$ m,
- density of occupants in the lower deck $p_{\text{low}} \in [0.1, 0.9]$.

For each simulation, the occupants' maximum velocities were generated from a truncated normal distribution $N(\mu_{\text{vel}}, \sigma_{\text{vel}})$ capped at 0.5 m/s and 2.0 m/s. Agent diameters were generated from a truncated normal distribution $N(0.45, \sigma_{\text{diam}})$ capped at 0.34 m and 0.56 m.

The parameter $p_{\text{low}} \in [0,1]$ is probabilistic and can be interpreted as the probability of an occupant choosing a lower-deck seat (assuming that the rail-car is empty). The number $(1 - p_{\text{low}})$ is then the probability of an occupant choosing a seat in either the middle or the upper deck (weighted by the number of seats in each of the decks). In summary, each seat i was assigned the following weight w_i and a weighted random selection of seats (one for each occupant) was performed:

$$w_i = \begin{cases} p_{\text{low}} \text{ / (lower deck capacity)} & \text{if } i \text{ is in the lower deck} \\ (1 - p_{\text{low}}) \text{ / (middle + upper deck capacity)} & \text{if } i \text{ is not in the lower deck} \end{cases}$$

The number of passengers on the lower deck can be roughly estimated as $p_{\text{low}} \cdot n$, where $n = 46$ is the number of agents.
The calculation of the sensitivity indices and the sampling method in the parameter space were implemented in SALib, a sensitivity analysis library in Python [33] using `SALib.sample.saltelli.sample` and `SALib.analyze.sobol.analyze` methods. The sampler's `N` argument, which dictates the number of samples, was set to 64. For each parameter configuration, the simulation process was run three times with newly generated values (from the same distribution) for each occupant in order to account for the randomness of the process. The results were then averaged. This led to a total of 3840 different simulations and 1280 points to estimate the sensitivity indices for each exit width. The first-order sensitivity indices S_1 and total sensitivity indices S_T are shown in Table 2. The second-order indices S_2 were close to zero and are burdened with a high degree of uncertainty. Scatter plots that illustrate the relationship between evacuation time and individual variables are shown in Figure 1.

Table 2: First-order sensitivity indices and total sensitivity indices for different exit widths.

	μ_{vel}		σ_{vel}		σ_{diam}		p_{low}	
	S_1	S_T	S_1	S_T	S_1	S_T	S_1	S_T
0.65m	0.793	0.955	0.078	0.130	0.044	0.099	0.090	0.155
0.90m	0.535	0.615	0.013	0.123	-0.001	0.083	0.270	0.396
1.34m	0.437	0.528	0.042	0.117	0.001	0.045	0.476	0.583

The mean of the velocity distribution μ_{vel} had the highest impact on the TET for exit widths of 0.65 m and 0.90 m according to both its S_1 and S_T index. Its relative importance, however, decreases as the exit width increases and parameter p (density of occupants on the lower deck) took over as the most important variable. This can be also seen in the accompanying scatter plots. More passengers sitting on the lower floor which is closer to the exit had a positive effect on the evacuation time. The variables σ_{vel} and σ_{vel} did not have a large first-order effect on the model; however, they were present in higher-level interactions. With exit widths of 0.65m and 0.90m, the difference between S_1 and S_T was larger which suggests the presence of higher-level interactions. With exit width of 1.34 m, this gap significantly shrank to the point where the S_1 index was approximately equal to the S_T index. This means that as the exit width increases the underlying model becomes simpler.

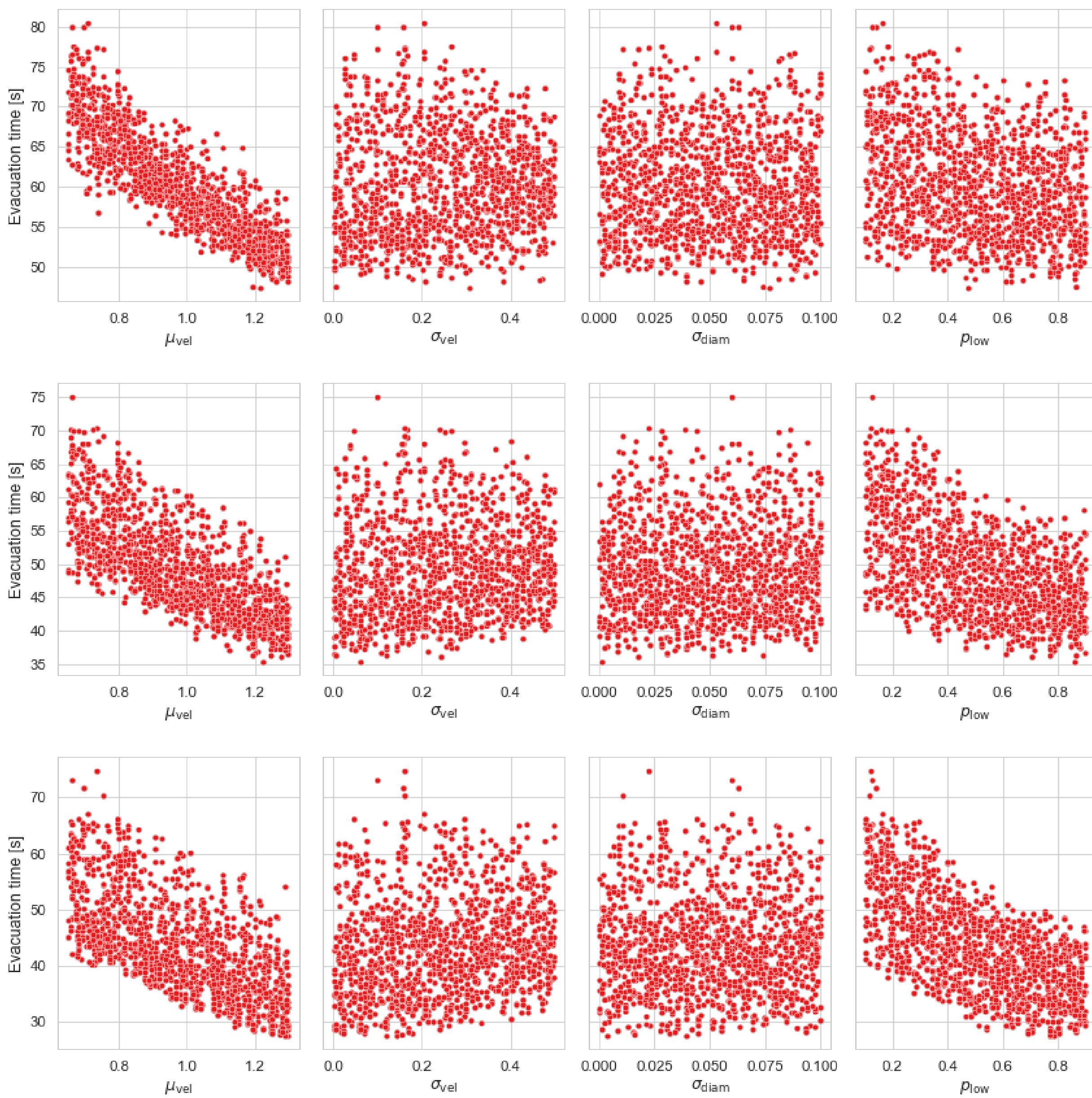

Figure 5: Relationships between the TET and the individual variables. The rows correspond to the exit widths of 0.65 m, 0.90 m, and 1.34 m.

CONCLUSIONS

This paper identifies several challenges encountered by the authors while building a model of rail-car evacuation in Pathfinder software: specifically defined seating positions, cramped environment with narrow aisles, and non-standard exit paths. These challenges were researched and their solutions were presented and applied to a case study that relies on experimental data. The addressed features were investigated by means of sensitivity analyses bringing some insight into this issue. To perform the presented study, the authors proposed a technique of repetitive simulations using a developed Python script running the simulations via a command line. This approach allowed to control three sources of randomness identified: variance in initial seating positions, variation in agents' parameters, inherent randomness of the model. The influence of these sources was investigated for various specific rail-car evacuation scenarios.

Based on the analysis of the influence of using a fundamental diagram (SFPE curve), the authors conclude that the application of the default curve in the specific rail-car environment overestimates the expected evacuation times, especially in the cases of wider exits allowing staggered or even independent motion of two passenger lines. A further experimental study related to proper fundamental diagrams for such cramped environments is deemed to be needed.

Considering non-standard exit types, the main challenge was to model a high jump to an open line without any equipment, especially when introducing a heterogeneous crowd. The proposed solution to reflect the delays of passengers with movement limitations (caused by hesitation before and balancing after the jump) used the Pathfinder feature to make agents wait a certain period after reaching a defined area.

Finally, a special focus was given to the influence of the seating positions of passengers in the rail-car. Our analysis showed that the initial positioning of the agents played an important role in the evacuation processes and should therefore be highly considered, as the influence of the seating distribution prevailed over the influence of the distribution of the maximal velocity of the agents in certain cases. A future study of seating preferences with respect to various types of passengers would help addressing this issue and may be the subject of further research.

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